A Requirements Framework for the Design of Smart City Reference Architectures

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Abstract

Reference architectures are generalized models of several end systems that share one or more common domains. They facilitate the design of high-quality concrete architectures and the communication between domain professionals. The reference architecture approach should be applied in the smart city domain because of its complexity where different stakeholders and heterogeneous systems and technologies must coexist and interact. Smart cities reference architectures should offer a cooperative framework for stakeholders and a guide to design concrete architectures. Industry and academia have proposed different requirements for concrete architectures. However, there is a lack of standardization in the requirements for the design of smart city reference architectures. This can produce that concrete architectures do not meet citizens' requirements. The goal of this paper is to define a set of requirements for the design of smart city reference architectures. We conduct a literature review to find the requirements which should fulfil these reference architectures.

1. Introduction

The Internet of Things (IoT) is a paradigm where smart objects, services, and applications are connected through the Internet to collect and produce useful information [1]. The IoT finds application in many different domains such as transportation, healthcare, industrial automation, emergency response, etc. [2]. Smart cities are complex systems, often called "systems of systems" [3] where IoT can play a significant role to ensure the delivery of desired smart services [4]. A smart city aims to address needs of multiple stakeholders using Information and Communication Technologies (ICT) to support its development [5].

Reference architectures are generalized architectures of end systems for an application domain [6][7]. This approach should be applied in the smart city domain due to the complexity of its end-systems and technologies. Smart cities reference architectures should provide rules, guidance, and policies to design concrete architectures [8]. These concrete architectures include components to model different city concerns and to guarantee interoperability between heterogeneous systems. Smart cities require the constant development of high-quality e-services in an integrated and autonomous environment in order to improve the quality of life for the citizens [9]. To support the development of smart cities, industry and academia have proposed different requirements for the design of concrete architectures [10][11]. However, there is a lack of standardization in the requirements for the design of smart city reference architectures.

This lack of standardization causes that smart city platforms do not support several key requirements (i.e. some reference architectures for IoT lack of elements for dynamic adaptation) [12]. References architectures can fail to provide a solid foundation to develop city solutions which meet the requirements of stakeholders and systems [13]. This paper explores and defines a set of requirements to mitigate this lack of standardization and to guide the design of reference architectures for smart cities. Researchers and practitioners can use these requirements as a comprehensive foundation to make more effective design decisions.

The remainder of the paper is organized as follows: Section 2 presents the research approach. Section 3 introduces the background of this work regarding the design of reference architectures. Section 4 defines the requirements for various smart city systems and platforms. Section 5 presents a discussion of the selected requirements. Finally, section 6 concludes the paper and proposes future directions for this work.

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2. Research approach

The goal of this paper is to define a set of requirements for the design of smart city reference architectures. A comprehensive literature review is performed to select these requirements and to achieve this objective. The next steps detail the search process and results following the concept-centric approach for literature reviews proposed by Webster and Watson [14]:

- Identify relevant journal articles. More than 15 journal articles were collected by querying scholarly databases (i.e., Google Scholar, IEEE Xplore, ACM Digital Library and Springer Link) for the terms "Smart City Requirement" and "IoT Requirement".
- Review the citations of the articles identified in the previous step (40 articles were collected).
- Review articles citing the key articles identified in the previous steps (20 articles were collected).
- Select the articles which contain a list of defined and clear requirements for smart cities and requirements for IoT platforms that should be applied in the smart city context. These articles were published between 2013 and 2017 which is probably the most recent period with a complete set of research for smart cities and IoT.
- In total 10 contributions were selected. They represent a high-quality collection of journal, conference and workshop articles and international standards such as IEEE.
- A concept matrix compiles these selected articles and presents 12 functional requirements and 16 non-functional requirements of end-systems for the design of smart city reference architectures. The definition, analysis, and impact of these requirements are presented in the next sections.

3. Background

Reference architectures have been designed in several domains impacting the productivity and quality of the systems [15]. The design of a reference architecture includes establishing the requirements of the reference architecture. Figure 1, illustrates how these requirements can be defined by considering the set of requirements of the systems that are intended to be produced based on the reference architecture. The identification of the systems requirements involves functional and non-functional requirements of existing or envisioned systems in the application domain.

Such requirements must reflect the processes, activities, and tasks that must be automated by the systems to be built from the reference architecture. The set of requirements of the reference architecture as well as a set of concepts are the inputs for the reference architecture design [15].

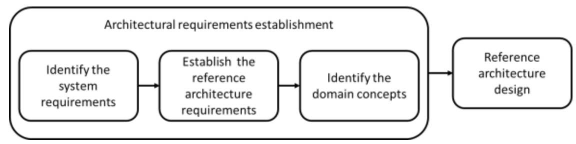

Figure 1. Architectural requirement establishment and reference architecture design [15]

These requirements are also relevant in the design of reference architectures for smart cities. Santana, Eduardo Felipe Zambom, et al. [16] extract the main requirements, components and features from smart city platforms to derive a reference architecture that facilitates the development of smart city applications. Each level in the reference architecture supports some functional and non-functional requirements. For instance, the cloud and networking level is responsible for the management and communication of the city network nodes. This level ensures some fundamental non-functional requirements, including scalability and extensibility.

Various Internet of Things (IoT) architectures have been proposed to integrate and support Information and Communication Technologies (ICT) solutions for smart cities [17]. The reference architecture for IoT, the IoT ARM [18] groups the requirements for the IoT systems in four perspectives, see Figure 2. These perspectives guide the architectural decisions that are common to more than one view in the reference architecture. Such perspectives include the requirements of concrete system architectures to ensure the quality of a real IoT system.

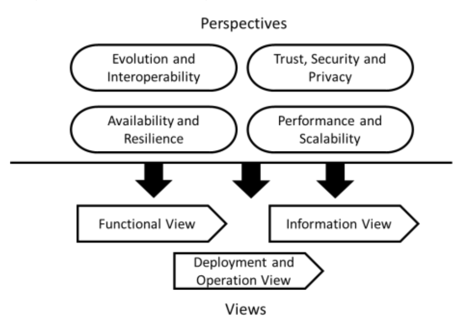

Figure 2. IoT ARM: perspectives and views [18]

Cavalcante et al. [12] define a set of requirements for the IoT platforms and systems based on the needs of users and applications. This set of requirements is compared with two reference architectures for IoT: the IoT ARM [18] and the reference architecture designed by the WSO2 company [19]. The analysis shows that such reference architectures do not fulfil completely all requirements in the IoT context, even though these requirements are considered essential for the IoT platforms and systems.

In the next section, this paper defines the functional and non-functional requirements of end-systems for the design of smart city reference architectures.

4. Requirements of smart city systems

This section defines the requirements of end-systems for the design of smart city reference architectures. The review explores the requirements for smart cities and requirements for IoT platforms that should be applied in the smart city context. The set of requirements are summarized in a concept matrix.

4.1. System functional requirements

The requirements for smart city systems are classified as both functional and non-functional. First, in this section, the focus is on key functional requirements. They capture the main functionalities of smart city systems as follows.

1) *Resource discovery:* Users, services, and devices require finding dynamically resources on the network at any time. The resources include heterogeneous hardware devices, devices' power and memory, analogue to digital converter devices, the communications module available on those devices and the services provided by these devices. This resource discovery should be automated because of human intervention for resource discovery is no viable. [12], [20], [21].
2) *Resource management:* Applications require providing services that manage the resources. Resource usage should be monitored, resources allocated in a right manner, and resource conflicts solved. In IoT architectures, especially in service oriented or virtual machine (VM)-based architectures, middleware needs to facilitate resource (service) composition, to satisfy users and applications needs [12], [16], [20]–[23].
3) *Data management*: Users and applications require managing large volumes of data generated by devices and transmitted through the network infrastructure. A smart city system needs to provide data management services to applications, including data collection, data streaming and processing, and data storage [12], [16], [20]–[25].
4) *Event management:* Smart city systems need to control events in progress (i.e. events generated in IoT applications) and to produce timely responses to that stream of events. Event management should provide a real-time analysis of data so applications can use accurate and real-time information [20], [21].
5) *Code management:* The smart city environment requires providing code allocating and code migration services. Code allocation selects the set of devices to be used to complete a user or application level task. Code migration transfers the code from one device to another one in the network [20].
6) *Application run-time:* Smart city platforms require managing the execution of their applications. The aim is to facilitate the deployment and integration of smart city applications. Some platforms provide a complete environment for developers to deploy their applications. Other platforms offer an execution run-time service for applications with tools that the platforms provide [16].
7) *External data access:* Smart city platforms require providing an interface to data access from external applications. The most common approach is an application program interface (API) to access the data collected from the city. Some smart city platforms use the concept of data as a service to make the data available to users and applications [16].
8) *Software engineering tools*: Smart city platforms require providing a set of tools for the development and maintenance of services and applications. Some platforms provide workflow design and analytics tools to facilitate the development of data visualization and the dynamic creation of reports [16].
9) *Definition of a city model*: Users need to facilitate the management and integration of the data collected from the city sensor network. The city model is used to guide the design of data queries and to represent the city data flows [16].
10) *Definition of business models:* The changes in the city and in technology imply changes in business models. The IoT drives the development of new business models to achieve competitive advantage through better information and more effective decision making [26].
11) *City Oriented:* Smart city systems should offer valuable services and applications that affect the city and every domain separately. The main

purpose is to improve the everyday life of citizens and increase public safety [25].

12) *Cost minimization:* Smart cities require optimizing the operational cost (i.e. development, installation, maintenance) and the resources by developing new energy-efficient solutions. Service providers and developers must consider this requirement in the implementation of devices and services [24].

4.2. System non-functional requirements

Key non-functional requirements of smart city systems capture quality support or performance characteristics as follows.

1) *Scalability:* A smart city system needs to be scalable to respond effectively when the system increases in the volume of sensor data flowing, in the volume of data being stored in databases, in the number of devices handled by the management system, in the number of data processed by services and applications, and in the number of applications and users. A substantial number of devices, services, applications, and users should be considered [12], [16], [20]–[22], [24].
2) *Security:* Smart city systems need to include security as a critical in the operation. Security needs to be considered during capturing, storing, transferring, aggregating and processing the data of things, as well as to the provision of services in the city. The security requirements include data confidentiality and authentication, access control within the IoT network and the enforcement of security policies [12], [16], [20]–[24], [26], [27].
3) *Trust:* Stakeholders and users require having confidence that the smart city systems/devices process and handle the data according their needs and rights. Trust management in smart cities helps people overcome perceptions of uncertainty and risk and engages in user acceptance and consumption on services and applications. Smart city systems should identify untrusted devices and implement policies to address problems of untrusted devices on the system [27] [28].
4) *Privacy:* Owners and users require the protection of their personal information related to their habits and interactions with other people and services. Privacy protection should be considered during capturing, transferring, storing, validating and processing data of devices [27].
5) *Availability:* Smart city systems require high availability in service provisioning, data management, communication, and sensing. Services need to be accessible and usable, especially if they support mission critical applications in the city [20] [21].
6) *Reliability:* Smart city systems require an appropriate level of reliability in technologies, devices, communication, service, and data management capabilities. The reliability is directly related to the consistent behaviour of the systems. The reliability of each component of the smart system finally helps in achieving system-level reliability [20] [21].
7) *Real-time:* Smart city systems can require real-time sensing and monitoring, intelligent processing and big data online analytics. For instance, process control systems, healthcare, and transportation need on-time delivery of their data and services. Real-time monitoring helps users to predict and to forecast various situations that can affect the city's prosperity [20], [23], [25].
8) *Interoperability:* Smart cities need to operate between heterogeneous components and systems. Systems function among sensors from multiple vendors, systems implemented in different languages, platforms that share data and users, and legacy systems that must communicate with the new platforms. Software platforms for smart cities adopt techniques to handle this requirement, such as adopting generic and standard interfaces or applying Semantic Web to integrate all platform components [12], [16], [20], [21].
9) *Context-aware:* Devices, services, and systems require being able to monitor its own environment in which they operate and events within that environment. Context-awareness is a key requirement to allow systems to offer better results using contextual information to users. Some smart platforms use data from users, such as location, activity, and language. Other platforms use data from the city, such as traffic condition, climate, and air quality [12], [16], [20], [21].
10) *Flexibility:* The smart city systems require providing different functionalities, depending on user needs and context. Service providers and developers need to consider certain flexibility from their software, products, and sensors for smart city applications [22] [24].
11) *Heterogeneity:* Smart city systems require managing the variety of devices, services, data formats, applications and communication technologies. This heterogeneity creates numerous challenges for the resulting smart city systems [21], [24], [25].

12) *Integrity:* smart cities need to make heterogeneous physical objects accessible on a large scale and to integrate them with the digital world. Some approaches based on SOA, propose integrated architecture incorporating various layers for application interface, service management, device management, security, and platform abstraction and devices layer [12], [23].
13) *Adaptability:* Smart city systems require providing high availability in service provisioning, data management, communication, and sensing. Dynamic adaptation ensures availability and quality of applications at execution time. Adaptability is related to context awareness. Many platforms adapt their behaviour based on the context to achieve fault-tolerance, select a closer server to improve efficiency, decide for batch or real-time processing, and adapt data from multiple data sources [12], [16], [21], [25]
14) *Extensibility:* Smart city systems need to add new functionalities, components, services, and applications to the platform anytime. This helps to ensure that these systems meet evolving city requirements and user needs [16].
15) *Configurability:* Smart city systems need to allow (re)configuration of their components. A smart city platform has many configuration options and parameters that define its behaviour at execution time. Configuration is useful for these environments where there are many and varied components that can change over time. This configuration should allow automatic configuration of devices and networks [16].
16) *Service-based:* Smart city systems require offering services and adding new functionalities easily in a flexible environment for application development. For example, a service-based middleware provides abstractions for the complex underlying hardware through a set of services (e.g., data management, reliability, security) needed by applications. [20] [23].

Table 1 compiles and synthesizes the functional and non-functional requirements for smart city systems. These key requirements can guide the design decisions to achieve more effective reference architectures.

Table 1. Requirements of systems and platforms for smart cities

Requirements	**Functional Requirements**												**Non-functional Requirements**															
References	Resource discovery	Resource management	Data management	Event management	Code management	Application run-time	External data access	Software engineering tools	Definition of a city model	Definition of business	City Oriented	Cost minimization	Scalability	Security	Trust	Privacy	Availability	Reliability	Real-time	Interoperability	Context-aware	Flexibility	Heterogeneity	Integrity	Adaptability	Extensibility	Configurability	Service-based
Cavalcante et al. [12]	X	X	X										X	X		X				X	X			X	X			
Santana et al. [16]		X	X			X	X	X	X				X	X		X				X	X				X	X	X	
Razzaque et al. [20]	X	X	X	X	X								X	X		X	X	X	X	X	X							X
UIT-T [21]	X	X	X	X									X	X		X	X	X		X	X		X		X			
Nitti et al. [22]		X											X	X								X						
Balamuralidhara et al. [23]		X												X		X			X					X				
Borgia [24]			X									X	X	X								X	X					
Kyriazopoulou [25]			X								X								X				X		X			
Whitmore et al. [26]										X				X		X												
Sicari et al. [27]														X	X	X												
Tot.	3	6	6	2	1	1	1	1	1	1	1	1	6	9	1	7	2	2	3	4	4	2	3	2	4	1	1	1
Tot. per Type	25												52															

The literature review also indicates that requirements are specified for different components of smart city systems such as middleware (MW), software platforms (PLT), data solutions (DAT), and business components (BUS). Table 2 reports these findings. Most of the requirements correspond to middleware and software platforms.

Table 2. Requirements according to the components of smart city systems

Requirement	MW	PLT	DAT	BUS
Resource discovery	X			
Resource management	X	X	X	
Data management	X	X	X	
Event management	X			
Code management	X			
Application run-time		X		
External data access		X	X	
Software engineering tools		X	X	
City model		X		
Business models		X		X
City Oriented				X
Cost minimization				X
Scalability	X	X	X	
Security	X	X	X	
Trust	X		X	
Privacy	X	X	X	
Availability	X			
Reliability	X			
Real-time	X			X
Interoperability		X		
Context-aware		X		
Flexibility			X	
Heterogeneity	X			
Communication		X		
Integrity		X		
Adaptability		X		
Extensibility		X		
Configurability		X		
Service-based	X			
Tot. per Type	14	17	9	4

5. Discussion

5.1. Requirements Analysis

The goal of this paper is to define a set of requirements for the design of smart city reference architectures. Through the literature review, 12 functional requirements and 16 non-functional requirements are identified. The results indicate that quality support or performance characteristics (e.g. scalability, security, privacy, interoperability, context-aware, adaptability) play a strong role in smart city systems and platforms. Functional requirements (e.g. resource discovery, resource management, data management, the definition of city and business models) are less common for all the systems reviewed. However, systems' designers must consider all functional requirements as well as non-functional requirements to meet citizens' needs [25].

Requirements both technical and user-centric must be satisfied by a smart city system [25]. The results of the literature review indicate that only a few smart city systems consider business components (see Table 2). Some common architectures for IoT systems present business components to manage the overall IoT system activities and services. The responsibilities of these components are to build a business model, graphs, flowcharts, etc. based on the received data from applications [2]. References architectures for smart cities must include these business components to facilitate the design of concrete architectures.

5.2. Requirements Implications

This paper aims to help researchers and practitioners as follows. First, for organizations that need to design a reference architecture for smart cities, understanding the requirements associated with the smart city systems. Second, the standardization of the requirements can help them to realize important advances in the design of more effective reference architectures and make industrial uptake of reference architectures research efforts easier. Finally, the set of requirements helps to meet the citizens' needs. For instance, the requirements related to cost minimization and optimization of resources by developing new energy-efficient solutions help to achieve the sustainability of the cities.

This set of requirements also helps to meet systems' requirements in different scenarios of smart cities. As an example, in terms of city model, "SmartSantander" which is one of the largest smart city experimental testbeds in the world has a platform that use a city model server for communicating with external applications. This city model defines the main components to connect the city platforms and external applications via Rest APIs [29]. Context awareness is the location-based services, such as a system in which different services are presented according to the location of a user. For instance, a person who goes to the airport requires the information about the smart services available. Based on this context, one smart application discovers video services for browsing the content of available video servers in the airport and other service informs to the person the time to board the plane [30].

6. Conclusions and further research

The design of a reference architecture includes establishing the requirements of the reference architecture. These requirements can be defined by considering the set of requirements of the systems that are intended to be produced based on the reference architecture. Industry and academia have proposed different requirements for the design of concrete architectures for smart cities. However, there is a lack of standardization in the requirements for the design of reference architectures. This paper explores and defines a set of requirements to mitigate this lack of standardization and to guide the design of reference architectures for smart cities. Through the literature review, 12 functional requirements and 16 non-functional requirements are identified.

The results indicate that quality support or performance characteristics play an essential role in smart city systems and platforms. Functional requirements are less common for all the systems reviewed. However, requirements both functional and non-functional must be satisfied because they help to meet citizens' needs and systems' requirements in the smart city context. Researchers and practitioners can use these requirements as a comprehensive foundation to make more effective architectural decisions. For example, common requirements such as security and privacy can be applied in more than one view in the reference architecture because systems need to prevent unauthorized users (i.e., humans and devices) to access services, applications, data, and devices.

As further steps for this research, existing smart city reference architectures will be explored based on this set of requirements. Moreover, it is important to define use cases in real scenarios to validate this proposal.

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8. References

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